P-RESONANT CONTROL FOR THE NEUTRAL POINT OF THREE PHASE INVERTER

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Specially dedicated to…

My parents, and my instructors who have helped me in difficult times, and I do not forget my friends who support me and help me in the duration of the projects. And the nameless people who counseled me, directly or indirectly.

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ABSTRACT

In this project, a Proportional resonant (PR) current controller is proposed to maintain a balanced neutral point for a three-phase four wire inverter, which can be used in microgrid applications. The neutral-point circuit consists of a conventional neutral leg and a split DC link. The neutral point is balanced with respect to the two DC source terminals (as required, in neutral-point clamped three-level converters) even when the neutral current is large so that the inverter can be connected to an unbalanced load. The controller, designed by using the Proportional resonant control techniques, which attain eliminate for the current flowing through the split capacitors. This leads to very small variation of the neutral point from the mid-point of the DC source, in spite of the possibly large neutral current. The simulation of inverter circuit, neutral-point and P-resonant has been performed using MATLAB/SIMULINK software. The simulation results confirm the validity of the proposed method, which can be seen as a promising that ensure P-resonant control suitable for microgrid applications.

ABSTRAK

Dalam projek ini, satu “Kadavan Hunan” pengawal arus bertujuan untuk mengekalkan titik neutral seimbang untuk tiga fasa empat wayar penyongsang, yang boleh digunakan dalam aplikasi microgrid. Litar pada titik neutral terdiri daripada kaki neutral konvensional dan kepada sambungan perpecahan di DC. Titik neutral adalah seimbang diantara dua terminal sumber pada DC (seperti yang dikehendaki, dalam penukar tiga tahap titik cengkam neutral) walaupun semasa neutral adalah besar supaya penyongsang boleh disambungkan kepada beban yang tidak seimbang. Pengawal direka menggunakan teknik kawalan salunan berkadar, yang akan menghapuskan arus yang melalui diantara celahan kapasitor. Keadaan ini akan membawa kepada perubahan yang sangat kecil di titik neutral dari titik pertengahan sumber DC, walaupun semasa neutral arusnya berkeadaan tinggi. Simulasi litar penyongsang, titik neutral dan P-salunan telah dilakukan dengan menggunakan perisian MATLAB / SIMULINK. Keputusan simulasi mengesahkan kesahihan kaedah yang dicadangkan, yang boleh dilihat sebagai satu cara untuk memastikan kawalan P-salunan sesuai untuk aplikasi microgrid.

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LIST OF SYMBOLS AND ABBREVIATIONS

DC	direct current
AC	alternating current
VFI	voltage fed inverter
VSI	voltage source inverter
CSI	Current source inverter
PR	Proportional Resonant
PWM	Pulse Width Modulation
ASDs	adjustable speed drives
SPWM	sinusoidal pulse-width modulation
VSCs	voltage-source converters
PI	Proportional integral
PID	Proportional Integral Derivative
PD	Proportional Derivative
FLC	Fuzzy logic controller
SVM	Space Vector Modulation

CHAPTER 1

INTRODUCTION

1.1 Project Background

A power inverter is an electrical power converter that changes direct current (DC) to alternating current
(AC); the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits [1]. A typical power inverter device or circuit will require a relatively stable DC power source capable of supplying enough current for the intended overall power handling of the inverter. Possible DC power sources include: rechargeable batteries, DC power supplies operating off of the power company line, and solar cells. The inverter does not produce any power, the power is provided by the DC source. The inverter translates the form of the power from direct current to an alternating current waveform. The level of the needed input voltage depends entirely on the design and purpose of the inverter. In many smaller consumer and commercial inverters a 12V DC input is popular because of the wide availability of powerful rechargeable 12V lead acid batteries which can be used as the DC power source. A power inverter device which produces a smooth sinusoidal AC waveform is referred to as a sine wave inverter. To more clearly distinguish from "modified sine wave" or other creative terminology, the phrase pure sine wave inverter is sometimes used. In situations involving power inverter devices which substitute for standard line power, a sine wave output is extremely desirable because the vast majority of electric plug in products and appliances are engineered to work well with the standard electric utility power which is a true sine wave. At present, sine wave inverters tend to be more complex and

have significantly higher cost than a modified sine wave type of the same power handling.

Three-phase inverters are used for variable-frequency drive applications and for high power applications such as HVDC power transmission. A basic three-phase inverter consists of three single-phase inverter switches each connected to one of the three load terminals. For the most basic control scheme, the operation of the three switches is coordinated so that one switch operates at each 60 degree point of the fundamental output waveform. This creates a line-to-line output waveform that has six steps. The six-step waveform has a zero-voltage step between the positive and negative sections of the square-wave such that the harmonics that are multiples of three are eliminated as described above. When carrier-based PWM techniques are applied to six-step waveforms, the basic overall shape, or envelope, of the waveform is retained so that the 3^{rd} harmonic and its multiples are cancelled[2].

Inverters can be broadly classified into two types, voltage source and current source inverters. A voltage fed inverter (VFI) or more generally a voltage–source inverter (VSI) is one in which the DC source has small or negligible impedance. The voltage at the input terminals is constant. A current–source inverter (CSI) is fed with adjustable current from the DC source of high impedance that is from a constant DC source. A voltage source inverter employing thyristors as switches, some type of forced commutation is required, while the (VSI) made up of using GTOs, power transistors, power MOSFETs or IGBTs, self-commutation with base or gate drive signals for their controlled turn-on and turn-off.

Since the neutral point of an electrical supply system is often connected to neutral, under certain conditions, a conductor used to connect to a system neutral is also used for grounding of equipment and structures. Current carried on a grounding conductor can result in objectionable or dangerous voltages appearing on equipment enclosures, so the installation of grounding conductors and neutral conductors is carefully defined in electrical regulations. Where a neutral conductor is used also to connect equipment enclosures to earth, care must be taken that the neutral conductor never rises to a high voltage with respect to local ground.

Proportional Resonant (PR) controller gained a large popularity in recent years in current regulation of grid-tied systems. It introduces an infinite gain at a selected resonant frequency for eliminating steady-state error or current harmonics at that frequency. However the harmonic compensators of the proportional resonant controllers are limited to several low-order current harmonics, due to the system instability when the compensated frequency is out of the bandwidth of the systems[3].

1.2 Problem Statements

Many power electronics applications, such as Distributed Generation systems, Uninterruptible Power Supplies or active filtering, employ an inverter feeding a star connected three-phase load with accessible neutral terminal. The currents flowing on each phase are generally not balanced so, if a transformer is not required, a connection to the neutral terminal should be provided by adding an extra wire to the inverter.

The neutral line is usually needed to provide a current path for possible unbalanced loads and the traditional six-switch inverter must be supplemented with a neutral connection. If the neutral point of a four-wire system is not well balanced, then the neutral-point voltage may deviate severely from the real midpoint of the DC source. This deviation of the neutral point may result in an unbalanced or variable output voltage, the presence of the DC component, larger neutral current or even more serious problems. Thus, the generation of a balanced neutral point in a simple and effective manner has become an important issue.

1.3 Project Objectives

i. To develop and simulate the neutral point connection for DC-AC inverter.
ii. To develop proportional resonant controller that suitable for neutral point for three phase inverter.
iii. To have zero current flows for the capacitor link at neutral point.

1.4 Project Scopes

i. Modelling of three phase DC-AC inverter with neutral point connection that will be modelled using MATLAB Simulink software.

ii. P-resonant control with Sinusoidal Pulse Width Modulation (SPWM) technique will be used to control the switching signals for the switches at neutral point connection

iii. Using the P-resonant control technique as controller to reduce the current flow at capacitor link in neutral point using MATLAB.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter is a general introduction to the neutral point of three phase inverter and it also focus on proportional resonant controller. The basic components and their detailed functions will be introduced and discussed.

2.2 Inverters

Inverters can be found in a variety of forms, including half bridge or full bridge, single phase or three phases. In pulse width modulated (PWM) inverters the input DC voltage is essentially constant in magnitude and the AC output voltage has controlled magnitude and frequency. Therefore the inverter must control the magnitude and the frequency of the output voltage. This is achieved by PWM of the converter switches and hence such converters are called PWM converters.

The DC-AC inverters usually operate on Pulse Width Modulation (PWM) technique. The PWM is a very advance and useful technique in which width of the gate pulses are controlled by various mechanisms. PWM inverter is used to keep the output voltage of the inverter at the rated voltage (depending on the user's choice) irrespective of the output load. In a conventional inverter the output voltage changes according to the changes in the load. To nullify this effect of the changing loads, the PWM inverter correct the output voltage by changing the width of the pulses and the output AC depends on the switching frequency and pulse width which is adjusted according to the value of the load connected at the output so as to provide constant rated output.

2.2.1 Voltage Source Inverter

The type of inverter that most commonly used is voltage source inverter (VSI) where AC power provides on the output side function as a voltage source. The input DC voltage may be an independent source such as battery, which is called a 'DC link' inverter. These structure are the most widely used because they naturally behave as voltage source as required by many industrial application, such as adjustable speed drives (ASDs), which are the most popular application of inverters Figure2.1 shows the voltage source inverter. Single phase VSIs are used in low range power application where the three phase VSIs is used in medium to high-power application. The main purposes of three-phase VSIs are to provide a three-phase voltage source, where the amplitude, phase and frequency of the voltage should be controllable [4].

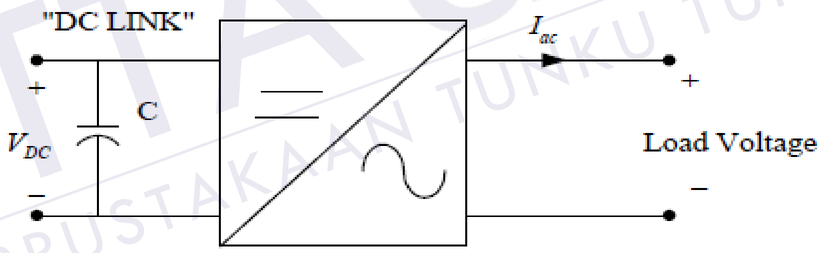

Figure2.1: Voltage Source Inverter (VSI)

2.2.2 Current Source Inverter

Respectively, CSI the DC source appears as a constant current and the voltage is changing with the load. The protection filter is normally a capacitance in parallel with the DC source The main advantage of the current source inverter is that it increases the voltage towards the mains itself. Figure 2.2 shows the current source inverter [5].

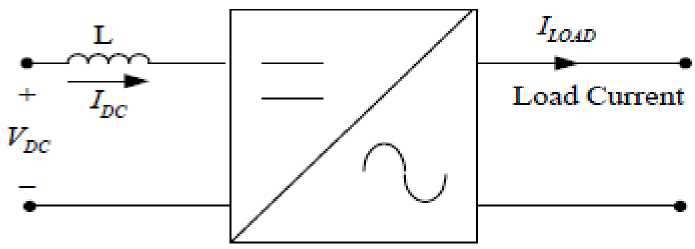

Figure2.2: Current Source Inverter (CSI)

2.3.1 Three-Phase Inverter

The dc to ac converters more commonly known as inverters, depending on the type of the supply source and the related topology of the power circuit, are classified as voltage source inverters (VSIs) and current source inverters (CSIs). Three-phase counterparts of the single-phase half and full bridge voltage source inverters are shown in Figures 2.3 and 2.4. Single-phase VSIs cover low-range power applications and three-phase VSIs cover medium to high power applications. The main purpose of these topologies is to provide a three-phase voltage source, where the amplitude, phase and frequency of the voltages can be controlled. The three-phase dc/ac voltage source inverters are extensively being used in motor drives, active filters and unified power flow controllers in power systems and uninterrupted power supplies to generate controllable frequency and ac voltage magnitudes using various pulse width modulation (PWM) strategies. The standard three-phase inverter shown in Figure 2.4 has six switches the switching of which depends on the modulation scheme. The input dc is usually obtained from a single-phase or three phase utility power supply through a diode-bridge rectifier and LC or C filter.

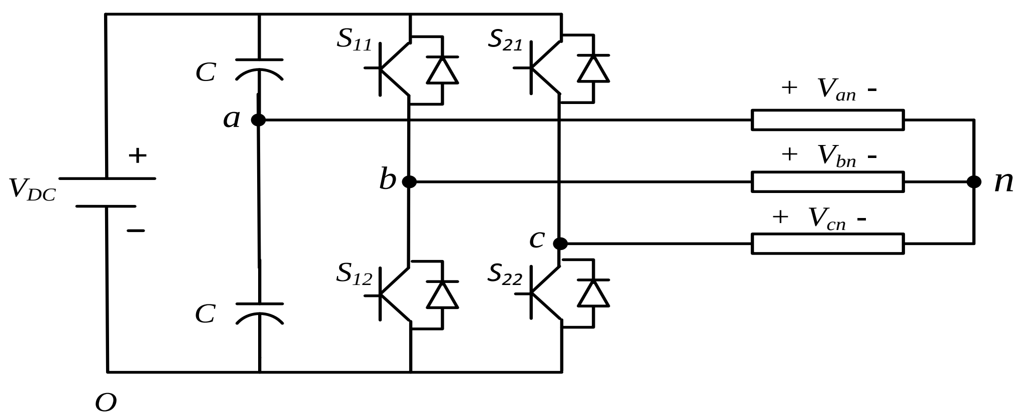

Figure 2.3: Three-Phase Half Bridge Inverter

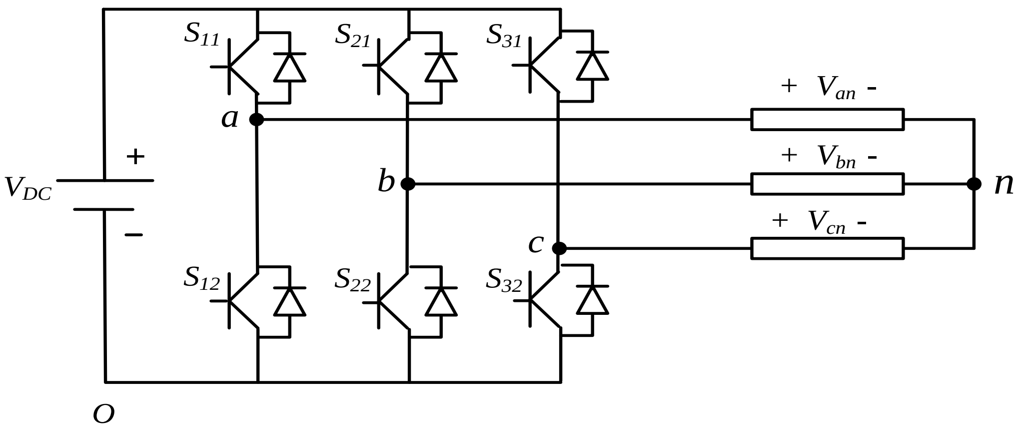

Figure 2.4: Three-phase Full –Bridge Inverter

2.3.2 Sinusoidal PWM in Three-Phase Voltage Source Inverters

The voltage source inverter that use PWM switching techniques have a DC input voltage (V_{DC} = V_S) that is usually constant in magnitude. The inverter job is to take this DC input and to give AC output, where the magnitude and frequency can be controlled. There are several techniques of Pulse Width Modulation (PWM). The efficiency parameters of an inverter such as switching losses and harmonic reduction are principally depended on the modulation strategies used to control the inverter[6]. The sinusoidal pulse-width modulation (SPWM) technique produces a sinusoidal waveform by filtering an output pulse waveform with varying width. A high switching frequency leads to a better filtered sinusoidal output waveform. The variations in the amplitude and frequency of the reference voltage change the pulse-width patterns of the output voltage but keep the sinusoidal modulation. As shown in Figure 2.5.

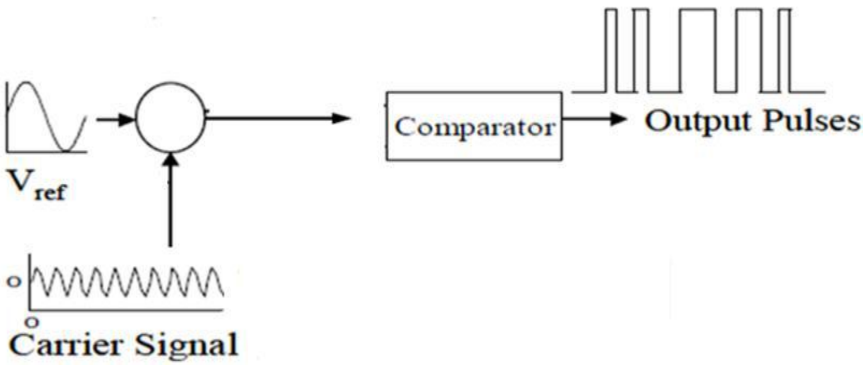

Figure 2.5: Block diagram for generation of SPWM pulses

As in the single phase voltage source inverters PWM technique can be used in three-phase inverters, in which three sine waves phase shifted by 120° with the frequency of the desired output voltage is compared with a very high frequency carrier triangle, the two signals are mixed in a comparator whose output is high when the sine wave is greater than the triangle and the comparator output is low when the sine wave or typically called the modulation signal is smaller than the triangle. This phenomenon is shown in Figure 2.6. As is explained the output voltage from the inverter is not smooth but is a discrete waveform and so it is more likely than the output wave consists of harmonics, which are not usually desirable since they deteriorate the performance of the load, to which these voltages are applied [7].

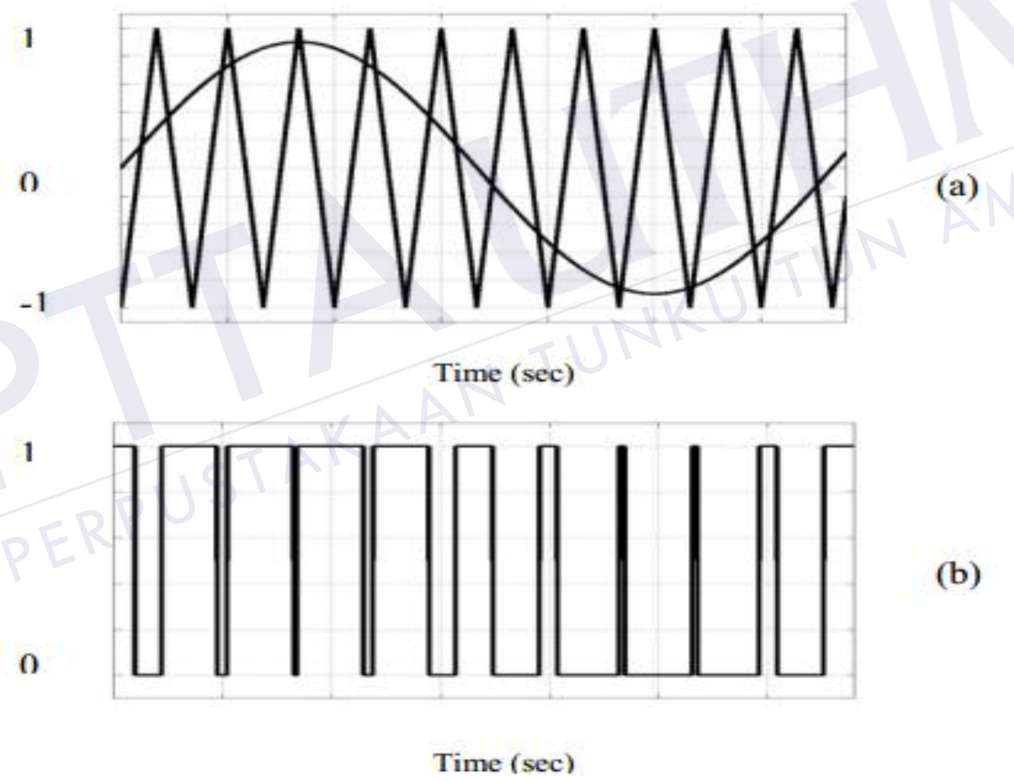

Figure 2.6: PWM illustration by the sine-triangle comparison method (a) sine-triangle comparison (b) switching pulses.

The gating signals can be generated using unidirectional triangular carrier wave as shown in the Figure2.7 But a pulse width modulated inverter employing pure sinusoidal modulation cannot supply sufficient voltage to enable a standard motor to operate at rated power and rated speed. Sufficient voltage can be obtained from the inverter by over modulating, but this produces distortion of the output waveform. The linear output range of SPWM is restricted to 0.785 compared with six step inverter. The non-linear region operation (over-modulation) is leading to large amounts of sub carrier frequency harmonic currents, reduction in fundamental voltage gain and switching device gate pulse dropping [8].

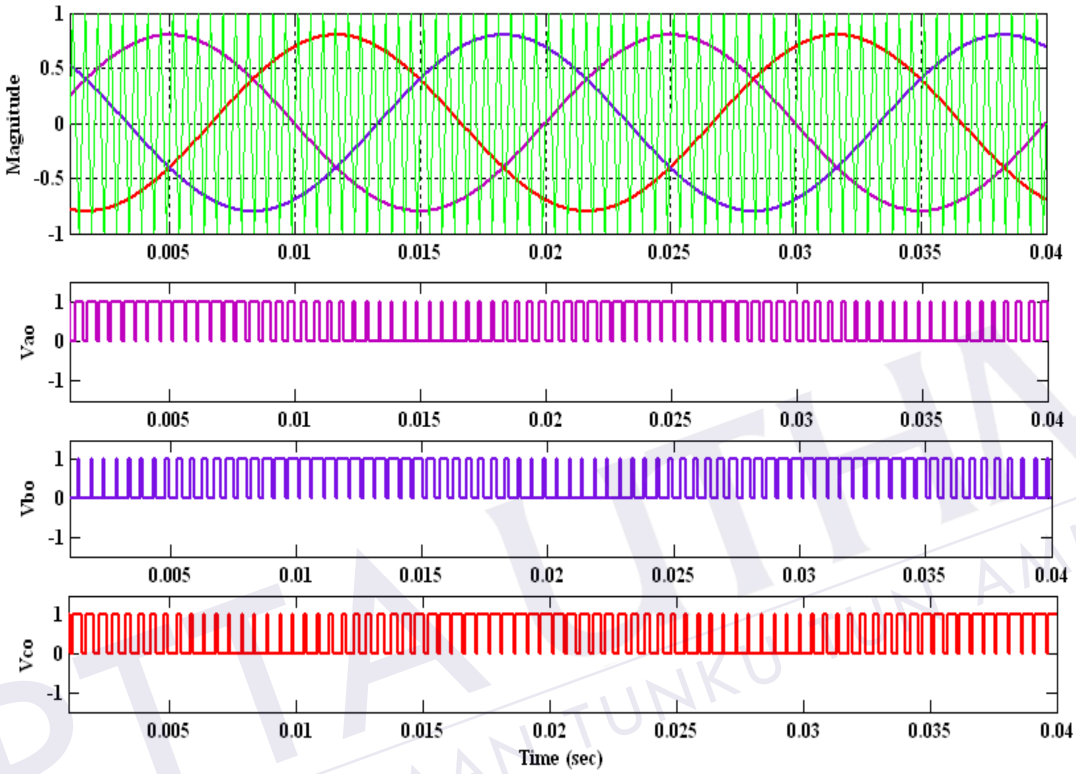

Figure 2.7: Carrier & Reference Waveform along with the pulses of Sinusoidal Pulse Width Modulation

2.3.3 Neutral point connection

The principles for the physical layout of three phase inverters, also known as voltage-source converters (VSC:s) are shown in Figure 2.8 The bridge is connected to the DC-link, whose voltage is raw material in the creation of the three-phase output voltage. The link voltage is from now on called dc-link. The mid potential of the dc-link is defined as neutral

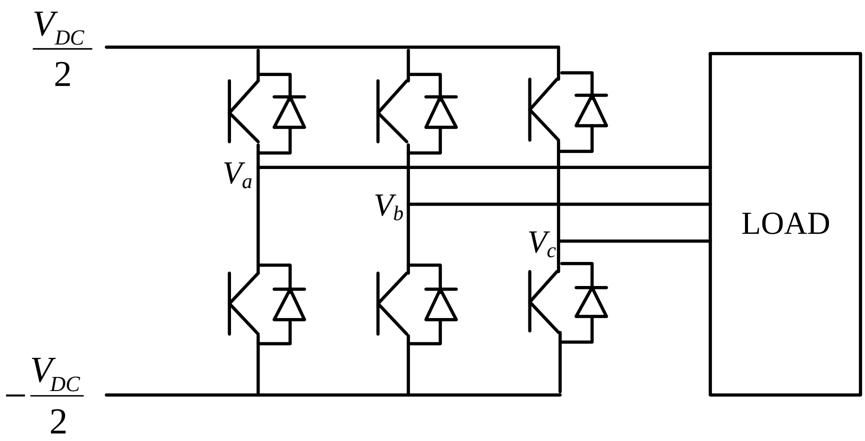

Figure 2.8: Three-phase inverter network.

Between the two poles of the dc link, the three half-bridges are connected. Each half bridge has two power electronic switches. By switching them, between fully conducting and fully blocking, the potentials of each half-bridge (V_a , V_b, V_c), with respect to the mid potential of the dc link, can attain /2 $\pm V_{DC}$.

This deviation of the neutral point may result in an unbalanced or variable output voltage, the presence of the DC component, larger neutral current or even more serious problems. Thus, the generation of balanced neutral point in a simple and effective manner has become an important issue. The neutral-point circuit consists of a conventional neutral leg and a split DC link. The neutral point is balanced with respect to the two DC source terminals (as required, e.g., in neutral point clamped three-level converters) even when the neutral current is large so that the inverter can be connected to an unbalanced load and/or utility grid. Three different circuit topologies have been widely used to generate a neutral point [9].

2.3.3.1 The split DC link

The first topology is a split DC link as shown in Figure 2.9, with the neutral point clamped at half of the DC link voltage. Since the neutral current flows through capacitors, high capacitance is necessary. Moreover, the neutral point usually shifts following capacitors and/or switches differences. To improve performance of the split DC link topology, different neutral point balancing strategies are reported, usually using redundant states of the Space Vector Pulse Width Modulation (SVPWM). In this solution, in is certainly the simplest one, but the three-phase inverter turns into three independent single-phase inverters. As consequence, zero-sequence harmonics are generated; moreover, specially when the load is unbalanced or non-linear, a high voltage ripple over supply capacitors is produced by neutral currents. A further limitation is represented by the maximum voltage value that the amplitude of each phase fundamental harmonic can reach. The main drawback is that the neutral point balancing is not fully decoupled from the three-phase converter control.

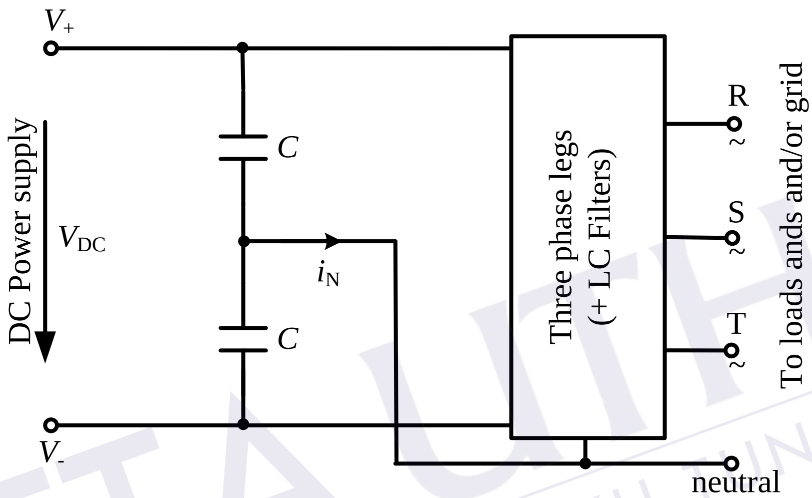

Figure 2.9: the split DC link

In a three-level NPC inverter, the capacitors splitting neutral point voltage has to maintain half bus voltage with respect to either positive or negative bus. However, the variation of neutral point voltage is inevitable especially when the neutral current is compensated [10].

2.3.3.2 Additional neutral leg

The second topology shown in Figure 2.10 is an additional fourth leg, called the neutral leg, is added to a conventional three leg converter. Various control strategies are available for this topology, however the additional neutral leg again cannot be fully independently controlled to maintain a stable neutral point.

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